Project Proposal

RoboQA-Temporal: Automated Temporal Quality Assurance for Autonomous Driving Datasets

1. Introduction and Motivation

Autonomous driving systems rely on large multimodal datasets combining LiDAR, camera, radar, and IMU sensors. These datasets fuel perception and sensor-fusion models, yet the quality of raw sensor data is rarely verified before training. In practice, many teams discover too late that model underperformance stems not from architecture choices but from poor data synchronization or sensor degradation.

Current tools such as Open3D or PCL allow engineers to view or filter point clouds but do not evaluate whether LiDAR and camera streams are **temporally aligned**. Similarly, ROS testing frameworks like HAROS focus on software nodes rather than data content. This lack of systematic data validation results in wasted GPU hours, inconsistent benchmarks, and unreliable reproducibility.

This project proposes **RoboQA-Temporal**, an open-source ROS2 framework that automatically detects **temporal desynchronization and data anomalies** in autonomous-driving datasets. The goal is to create a quality-assurance layer between *data collection* and *model training*—catching errors before expensive labeling or learning begins.

2. Problem Definition

Autonomous driving datasets can span hundreds of terabytes. Manual inspection of these rosbags for synchronization errors or sensor dropouts is infeasible. Research consistently points to this gap: an ACM 2024 study noted that “dataset quality assessment is performed primarily after data is published,” and IEEE papers on ROS quality assurance highlight the absence of runtime validation frameworks.

RoboQA-Temporal directly tackles this issue by automating the detection of:

- LiDAR-camera timestamp drift,
- temporal anomalies in point-cloud sequences, and
- degraded or missing sensor data.
  By assigning each sequence a **Temporal Fusion Quality Score (TFQS)**, the framework enables dataset curation and pre-training validation at scale.

3. Objectives

1. **Design** an automated, ROS2-native pipeline for evaluating multi-sensor temporal and spatial data quality.

2. **Develop** the TFQS metric combining timestamp consistency, calibration drift, and signal integrity.

3. **Implement** modules for temporal anomaly detection in point-cloud sequences.

4. **Integrate** the system into CI/CD-style data ingestion pipelines for continuous validation.

5. **Benchmark** quality results across datasets such as KITTI, nuScenes, and Zenseact Open Dataset (ZOD).

4. Related Work

Existing open-source and commercial solutions offer only partial support:

- **PCL / Open3D / PyTorch3D:** handle visualization and filtering, not synchronization checks.

- **HAROS / rostest:** validate ROS nodes, not the content or temporal alignment of rosbags.

- **3D-DaVa (2025):** detects defects in static industrial point clouds but is inapplicable to dynamic driving data.

- **Commercial platforms** (Scale Nucleus, Encord, Labelbox): focus on annotation quality, not raw sensor integrity.

To date, **no general, open-source tool validates temporal consistency across multi-sensor datasets** used in autonomous driving.

5. Methodology

System Overview

1. **Data Input:** Parse LiDAR, camera, and IMU topics directly from ROS2 bags.
2. **Timestamp Validation:** Cross-correlate frame times across sensors to measure drift.
3. **Anomaly Detection:** Identify sensor degradation through temporal density drops, exposure imbalance, and frame jitter.
4. **Scoring:** Compute TFQS (0–100) combining spatial and temporal quality indicators.
5. **Reporting:** Output JSON summaries and interactive dashboards for visual analysis.
6. **Pipeline Integration:** Implement automated quality gates within GitHub Actions or ROS2 launch tests.

Evaluation Plan

- Test datasets: KITTI, nuScenes, and ZOD.
- Validation metrics: TFQS correlation with perception accuracy (mAP, IoU).
- Controlled experiments introducing artificial timestamp drift to quantify detection precision.

6. Expected Outcomes

- A fully functional **RoboQA-Temporal** prototype integrated with ROS2.
- A standardized **TFQS metric** for multi-sensor dataset evaluation.
- A **visual dashboard** showing synchronization drift and sensor health.
- A **benchmark report** comparing quality across public autonomous-driving datasets.
- A potential short paper or poster submission describing the framework and results.

7. Project Timeline (8 Weeks)

Week	Task	Deliverable
1	Literature review, toolchain setup, dataset selection	Survey notes, prepared datasets
2	ROS2 data-parsing and timestamp extraction module	Prototype data-reader node
3	Develop temporal drift-detection algorithms	Baseline synchronization checker
4	Implement LiDAR-camera anomaly metrics (density, jitter)	Initial anomaly-detection module
5	Design and compute Temporal Fusion Quality Score (TFQS)	TFQS module integrated with drift detection
6	Build dashboard and reporting layer	Visualization interface and reports
7	Evaluate system on KITTI, nuScenes, and ZOD datasets	Experimental results and analysis
8	Final integration, documentation, and presentation	Complete framework + project report

8. Impact and Significance

This project aims to shift robotics data workflows from *quantity-driven* to *quality-driven*. By catching synchronization and data-integrity issues early, RoboQA-Temporal reduces computation costs, improves model robustness, and encourages transparent benchmarking across datasets.

The framework supports open-source robotics practices and aligns with emerging ISO data-quality standards (ISO/IEC 25012, ISO 8000-61). Its outcomes could benefit both research labs and industrial autonomous-vehicle developers, filling a well-recognized but unsolved gap in the field.

9. Selected References

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